GROWTH AND DEVELOPMENT OF A PURE STAND OF KOA (*ACACIA KOA*) AT KEAUHOU-KĪLAUEA

Roger G. Skolmen and David M. Fujii
Institute of Pacific Islands Forestry
Pacific Southwest Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture
Berkeley, California, stationed at Honolulu, Hawaii

In fall 1976, a 200-acre (80.9 ha) portion of a paddock adjacent to the Kīlauea Forest Reserve on Keauhou Ranch, island of Hawai'i, was selected by the land owners, the Bernice Pauahi Bishop Estate, to be used to test and demonstrate the conversion of woodland-pasture into a new koa (*Acacia koa* Gray) forest. The location was selected primarily because it was considered poor pasture land by Parker Ranch, which was then the lessee, and because it could be easily fenced to exclude cattle. About 30 acres had been logged by Blair, Ltd., and converted to open grass-woodland in the early 1960's. The other 170 acres were heavily logged in 1969 by Campbell-Burns. Cattle grazed in the area and as a result, about 50% of the forest was converted to grassland.

In spring 1977, the 200-acre area was fenced off and salvage-logged to remove the remaining merchantable koa trees. An initial 50-acre (20.2 ha) increment was cleared by members of the Kūlani Honor Camp between March and June 1977. A 10-acre (4 ha) corner section representative of the open grass-woodland type was left uncleared for comparison. Within a month after clearing, abundant natural koa seedlings began to emerge, particularly near koa stumps. Later, koa seedlings were planted in the areas where natural seedlings were scarce.

Two additional 50-acre increments were cleared: one in spring 1978, and the other a year later. All three of the clearing operations resulted in abundant natural regeneration.

It is well-known that abundant koa regeneration occurs after land clearing or fire (Judd 1935; Whitesell 1964). It was essentially a foregone conclusion that, barring a severe drought, this regeneration project would result in the establishment of a pure, even-aged stand. In addition, nursery-grown seedlings were available to plant if for some reason the natural reproduction failed. However, we know of no instance of a pure, even-aged stand of koa ever developing into a good merchantable timber stand. Therefore, this project afforded us an opportunity to follow the development of pure, even-aged stands from the beginning and to manage as necessary to produce good stands. We now have three years of data to report.

MATERIALS AND METHODS

Within a month of land clearing, we established reproduction plots. In the first 50-acre increment, we established 28 0.1-acre plots systematically at 200-foot intervals along two transects across the area. Three of these plots fell within the 10-acre uncleared corner section and the other 25 in the bulldozed area. We established four 0.001-acre natural reproduction plots within the 0.1-acre plots when we found that 0.1-acre provided much too large a sample of the abundant seedlings. For the planted trees, we found that one-fourth of each 0.1-acre plot provided an adequate sample. In the second two increments, we established 0.001-acre natural reproduction plots at 100-foot intervals along two transects across each area and selected two 0.1-acre plot locations in each area on which to follow the growth of planted seedlings.

The plots in the first increment were measured once a month for the first six months after establishment, then at three-month intervals for two measurements, and thereafter at six-month intervals. The plots in the other increments were measured only at six-month intervals. The oldest plots were established 2.5 years before the most recent measurements reported here. Measurements and observations taken of live trees on the plots were tree height; leaf form; ground cover immediately under the tree; vigor class; whether open-grown or shaded; and presence of insects, disease, or frost damage. All trees were permanently marked so their survival could be followed.

RESULTS AND DISCUSSION

Seedling Germination, Stocking, and Survival

In the first increment, bulldozing was started in March and completed in June 1977. The mauka (SW) half of the area was cleared in March and April and the makai (NE) half in May and June. We established plots on July 1, when the soil was dry and dusty to a depth of 6 inches. After two months, most germination had been completed in the mauka plots, whereas it was still progressing on the makai plots. Germination was essentially complete by August 1. Some seedlings were dying while others were germinating throughout the dry period.

On August 1, stocking of natural seedlings varied among the 0.1-acre plots from 60 to 22,000 per acre, with an overall average of 2600. We converted to 0.001-acre plots for natural reproduction in August and estimated 2823 seedlings per acre based on these smaller plots rather than the 2600 based on the 0.1-acre plots. We found 56% of the 0.001-acre plots stocked with at least one seedling, suggesting that at this time before planting, 44% of the area did not contain enough trees to provide 1000 trees per acre. After planting, 79% of the plots were stocked meaning only 21% of the ground had fewer than 1000 trees per acre in stocking.

A drought in August caused the stocking to drop from 2823 to 2312 natural seedlings per acre (Fig. 1). The main cause of mortality observed was moisture stress, although insect damage was present. For the rest of the year, the number of natural seedlings increased slightly, reaching 2440 per acre in December 1977, then dropping sharply to 2200 between January and March because of frost damage. Since then, there has been a very slight loss to make an average current level of 2030 trees per acre. The gradual loss appears to result mainly from competition for light among the trees.

In the second increment, plots were established in June 1978, just after planting had been completed. Rain fell daily throughout the preparation period, and seedling establishment was very high at 6942 per acre with 75% of the plots stocked with natural seedlings. This rate had increased to 7221 by January 1979 and since then has remained nearly the same, although it reached 7846 in December. This high survival is attributed to the very evenly distributed heavy rainfall of 1978 and 1979.

The third increment, first measured in May 1979, had 6680 seedlings per acre initially, with 81% of the plots stocked. During the ensuing six months this rate increased to 8940 per acre, although stocking of plots declined to 77%. During the first six months mortality averaged 526 seedlings per acre, which appeared to be caused mainly by pigs browsing. The increase in pigs may have resulted from the lack of human activity in the area and the proximity of this increment to the intact forest, where pigs are plentiful. The excellent growth of seedlings in this third increment can be attributed to the continuing wet weather throughout the period of establishment. During the first six months after clearing, no week had less than 2 inches of rainfall.

In all three increments, practically all seedlings that survived germinated on bare soil or shallow litter. Occasionally, seedlings were found emerging from thick debris, or at the edges of grass clumps missed in bulldozing, but usually these seedlings had disappeared by the time of the next measurement because the thick litter resulted in desiccation or the grass provided too much competition for light and moisture. The poorer stocking of the first increment is attributed to the drought periods during its establishment.

Seedlings germinated and grew under logs and in other completely shaded spots, but growth was very slow. A total of 15 root suckers were found on the plots, 14 on one plot--all from the same root--and one on another, so they were of rare occurrence.

Growth and Development

The height growth of natural seedlings in the first increment was only 9 inches in the first six months probably because of a prolonged germination period, occasional periods of dry weather soon after germination, and a particularly cold period with frost during the first winter (Fig. 2). In this same time interval, but with almost daily rainfall, growth in the second increment was 10 inches. In the third increment, growth after six months was only 8 inches, because almost one-third of the measured seedlings had only germinated during the 5-month period after the first measurement had been made; therefore, the seedlings were still very young and small.

A comparison of growth in the three increments indicates that, on the average, koa seedlings at the site can be expected to reach about two feet in the first year, six feet in the second year, and about 10 feet in the third year (Fig. 2). Exceptional trees measured were those that grew 23 inches at four months, 40 inches at six months, and 61 inches at one year. After nearly three years, the tallest tree on any of the plots stood about 25 feet. It was 18 feet (5.6 m) and 2.3 inches (5.8 cm) diameter at breast height (dbh) at 2.5 years of age. The largest dbh of any tree on the plots at 2.5 years was 2.9 inches.

The planted trees averaged 12 inches when planted. Two plantings were made in the first increment. In the first planting, all trees were fertilized by dropping small amounts of 10-30-10 in and around the planting hole. In the second planting, no fertilization was done. At first planting, the fertilized planted trees outgrew the natural seedlings, whereas the non-fertilized did not. By two years of age, however, the natural seedlings had outgrown the fertilized planted trees by one foot in height and had outgrown the non-fertilized trees by more than 3 feet.

Phyllodes had begun to develop on the natural seedlings at the six-month measurement; however, phyllode development was highly variable. The event seems to be controlled primarily by heredity but is also very strongly influenced by the amount of light received, as well as by site.

The good sites had greater stand differentiation than the poor sites. In April 1980, when the stands were 32 to 33 months old, we estimated the percentage of trees with phyllodes and of those that were dominant (i.e., emergent) trees, by site:

Site	% Trees with Phyllodes	% Dominant Trees
Good	80%	64%
Average	64%	76%
Poor	72%	100%

In January 1980, we found one tree on the plots flowering at 2.5 years of age--a 15-foot, 3-inch diameter tree. Several other trees of the same age were in flower at that time but did not fall on the plots. By April, the tree on the plot was developing pods, several of which looked like they would abort. This precocious tree was developing more flower buds in April. We will collect seed from these early flowering trees to use in breeding for early flowering.

Insects, Diseases, and Other Disturbances

The creation of this pure stand of even-aged koa in what has probably always been a mixed, all-aged forest is fraught with peril and it remains to be seen if an insect or disease that attacks a certain-age koa tree will build up to epidemic proportions and destroy the trees. So far, there is no indication of this happening.

The most serious disease present is the rust *Uromyces koae* Arthur ex Stevens, which in the three-year old increment, is found present on 36% of the trees. Occasionally, on about 5% of the trees, and then mostly on the poor sites, *Uromyces* has killed back the tree leader causing a lower bud to form a new stem. On the poorest site examined, *Uromyces* was infecting 60% of the trees; on the best site, it was infecting only 20%.

Another disease, *Pestalotia* spp., was found to be common on the best sites in April 1980. It was then causing necrosis of phyllode tips on up to 50% of the trees in some areas, but was totally absent from other areas of the same age. It did not appear then to be doing more than causing a slight reduction in growth.

Leaf insects were also quite noticeable in April, attacking the phyllodes on 40% of the trees in the most severely hit area of those observed. Other tip boring insects had taken out the tops of occasional trees, but did not appear to be causing a serious problem yet.

In general, insect and disease damage in all three increments appeared most severe in the more highly stressed areas. Such areas had obviously compacted soil, extremely rocky surface soil, or very deep litter. So far, the most severe loss of trees was due to a drought in mid-1977; the next most severe loss was due to frost in December 1977, when the trees were still too small to prevent ground frost from occurring. In January 1980, a severe windstorm hit the area but only caused uprooting of 10 or 20 trees in the first 50-acre increment.

Site Variation

The number of seedlings per unit land area in all three increments varies widely. Stocking is patchy, varying from zero to more than 20,000 trees per acre in patches of 0.1-acre or so in size. The reason for poor stocking in some areas is obvious. These areas were landing sites that received a lot of heavy equipment traffic which compacted the soil, inhibiting seedling germination and impeding drainage and root growth of the few seedlings that became established. Planted trees in these areas have not grown well, even when fertilized.

Other poorly-stocked areas appeared to be well suited for koa and we thought initially, were areas that just did not contain much seed. In many of these areas, however, planted trees have not grown any better than the sparse natural seedlings.

We extracted soil samples from eight good and poor sites and measured bulk density of six. Data on bulk density do not contribute much to our understanding. The surface soil bulk density ranged from 0.262 to 0.637 among the samples, and the differences between good sites and poor sites were not significant. This low bulk density is typical for these high organic matter soils. At 12-inch depths, the bulk density was slightly lower than at the surface, ranging from 0.241 to 0.455. Again, differences between good sites and poor sites at this depth were not significant either. The bulk density values suggest that some surface soil compaction had occurred on all sites, but had not inhibited seedling germination and survival.

The soil analyses showed no correlation between available nutrients, organic matter content, and good or poor site. Two of the three good sites had a much lower carbon to nitrogen ratio than any of the others. Nitrogen was relatively high, possibly because of fixation by the legume, koa. Cation exchange capacity was good in all samples, but base saturation was low.

In April 1980, to determine if foliar analysis should be undertaken, we collected lower branch tip foliage from one very vigorous tree on a good site, one typical tree on an average site, and one good tree on a poor site. The sample was much too small to provide any conclusions. The analyses indicated low potassium, sulfur, and aluminum, and high iron in both young and old phyllodes of the good tree; a somewhat high level of chlorine and aluminum in the young phyllodes of the poor tree, as well as a somewhat high level of calcium in the old phyllodes; and the anomalies of high nitrogen, phosphorous, potassium, and sulfur coupled with low calcium in the young and old phyllodes of the average tree. About all we can conclude from these analyses is that more sampling is needed.

In obtaining soil samples, we found standing water at about 8 inches in one landing area. This discovery suggested that poor drainage may be a cause of poor stocking in areas that were compacted by heavy traffic.

Reproduction Without Scarification

In April 1980, after cattle had been excluded from the area for slightly more than three years, we counted all seedlings three years or younger in 5 acres of the 10-acre corner section that had been reserved as an untreated control. We found 20 natural seedlings emerging from the dense kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.) cover. We estimated that there are 40 such trees in the 10-acre area or 4 per acre.

It appears likely that if cattle were completely excluded from Keauhou Ranch, the koa forest would gradually come back without any artificial help. But at the current rate, it will take at least 50 years to obtain stocking of about 50 trees per acre, which would be about the minimum needed to result in a mature forest containing 10 to 20 large koa trees per acre.

On National Park land adjacent to Keauhou Ranch, a healthy young koa-'ōhi'a (*Acacia-Metrosideros*) forest is developing on an area that was once heavily grazed. This growth is another indicator that koa forest can be regenerated simply by fencing out cattle.

CONCLUSIONS

So far, it appears that the objective of the Kīlauea-Keauhou Koa Forest Regeneration Project--to create a dense even-aged stand of koa--is succeeding. The trees in the oldest increment are growing rapidly over most of the land area and have not been damaged seriously by diseases or insects. They are beginning to shade out the grass beneath them which will provide a more natural understory environment in which other native species may be able to grow. The taller trees are now about 15 feet (4.5 m).

The trees of the second increment look similar to those of the first increment at that age. The stressed trees are attacked by rust and insects. The trees are more closely spaced than those of the first increment, and the taller of them are now about 10 feet (3 m).

The third increment, at one year, has trees up to five feet (1.5 m) tall and phyllode formation is just beginning. Little rust or insect damage has occurred.

LITERATURE CITED

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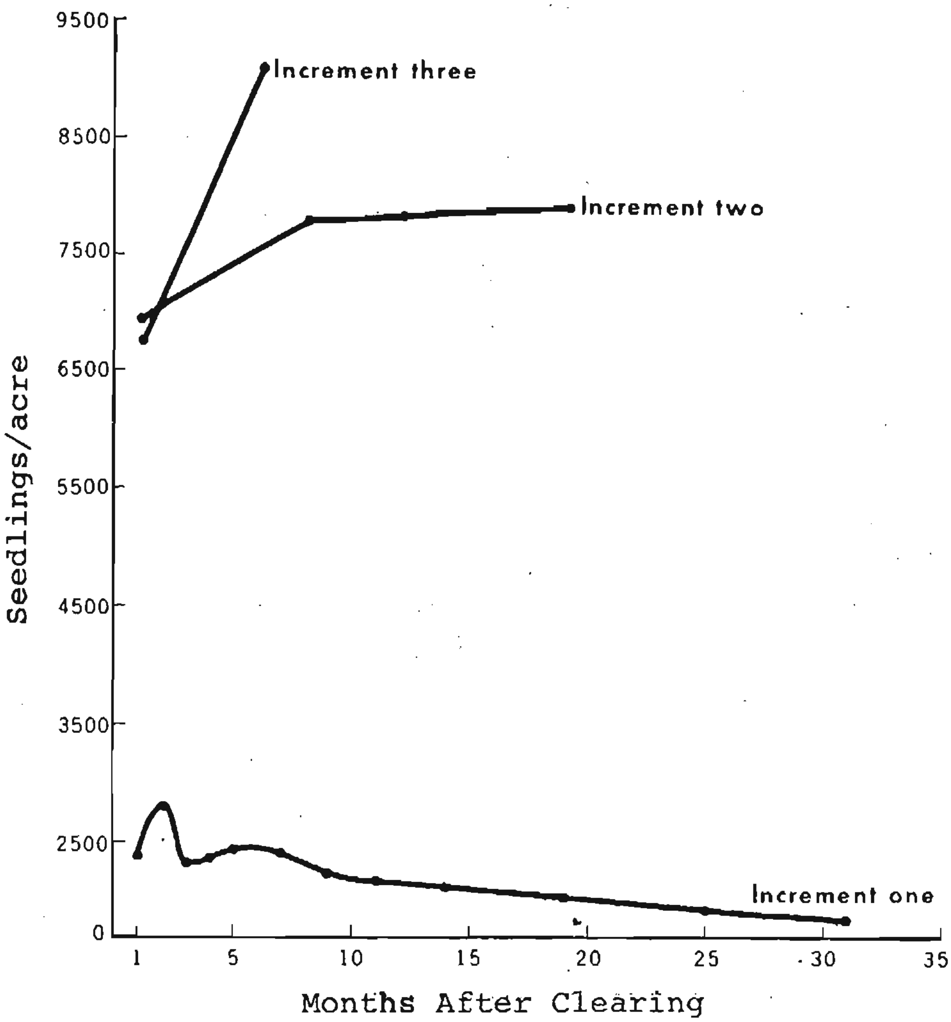

Figure 1--Changes in stocking of natural seedlings at the Kilauea-Keauhou Koa Regeneration Project after land clearing of three 50-acre increments.

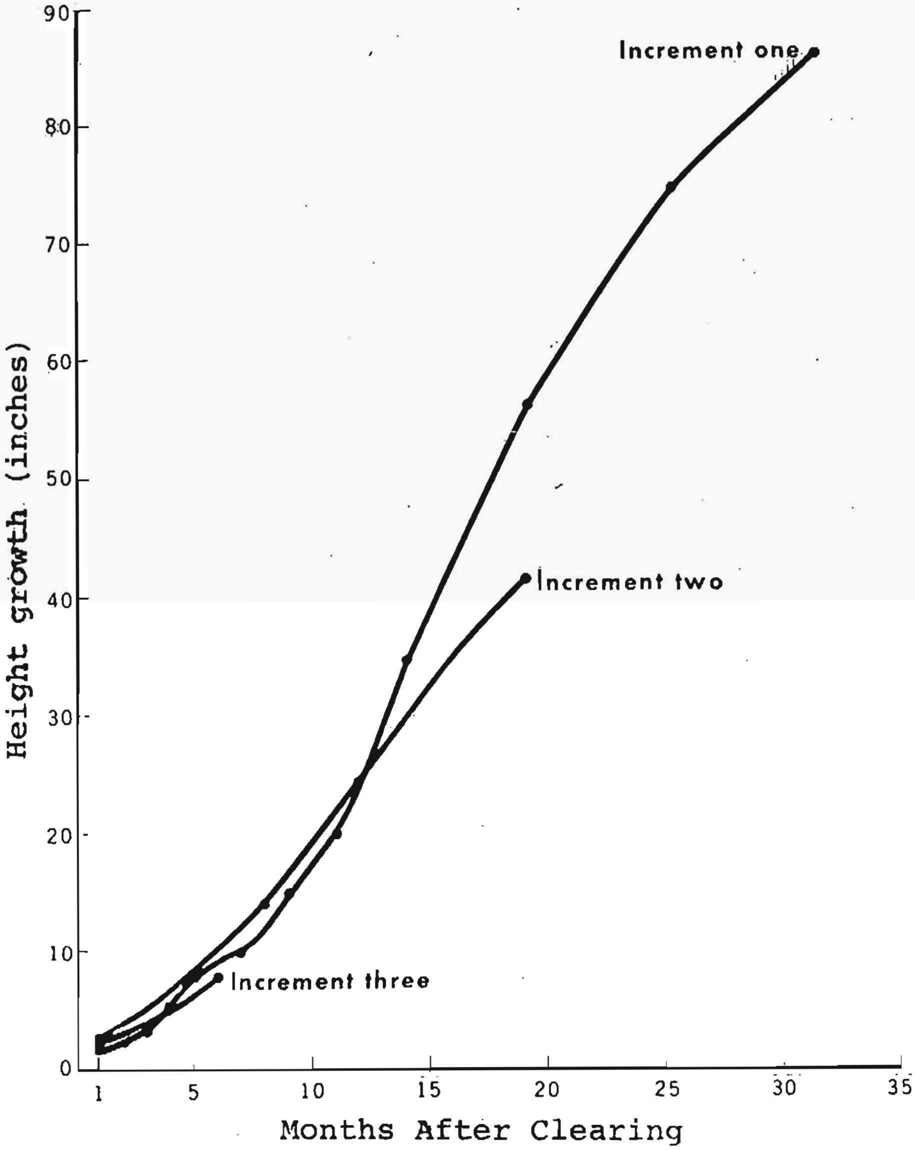

Figure 2--Height growth of natural seedlings at the Kilauea-Keauhou Koa Regeneration Project after land clearing of three 50-acre increments.